Neutron Diffraction Contributes to Improving the Fatigue Life of Bridges

Welded attachments to large-scale structures such as bridges can limit the serviceability and prevent effective use of high strength steels. To avoid this, it is desirable to enhance the fatigue resistance of common attachment details such as transverse stiffeners, cover plates, gusset plates and other welded details that, at the weld toe, are often the initiation point for crack growth.

Enhancement of fatigue resistance of welded joints by plastic deformation of the surface and by improvement of weld toe characteristics is well established [1, 2]. It is known that conventional improvement techniques such as grinding, shot peening, air hammer peening, gas tungsten arc re-melting, and use of improved welding consumables can improve fatigue resistance of welded details [3]. However, these procedures are time-consuming, and can be inefficient and environmentally unfriendly. Ultrasonic Impact Treatment (UIT) offers an alternative means to avoid the negative aspects of other methods [4].

The post-weld enhancement of welded details by UIT, developed by Statnikov and co-workers [4], involves deformation treatment of welds by impacts at ultrasonic frequency on the weld toe surface. The objectives of the treatment are to introduce beneficial compressive residual stresses at the treated weld toe zones, and to reduce stress concentration by improving the weld toe profile. UIT is claimed to involve a complex combination of strain hardening, reduction in welding strain, relaxation of residual stress, and a reduction in operating stress concentration, thereby achieving a deeper cold-worked metal layer. However, virtually none of the effects ascribed to UIT have been confirmed by appropriate measurements.

Here we highlight neutron diffraction measurements at the NCNR that have contributed new insights into how UIT actually affects residual stresses in the weld region around a full-scale cover plate for a steel girder. In Fig. 1 a diagram is shown of a typical I-beam fatigue-tested at the Center for Advanced Technology for Large Scale Structures (ATLSS) at Lehigh University. In the initial phase of the NCNR-Lehigh collaboration, neutron diffraction was used to determine the effect of UIT on a test flange plate by measuring before and after the treatment by UIT. The test plate consisted of a cover plate having a 12.5 mm (0.5 in.) end fillet weld attaching it to a base plate. This kind of cover-plate detail is often used in steel bridges but has a low level of fatigue strength compared to other welded configurations. The geometry and dimensions of the welded detail are the same as in the full-scale fatigue test beams of Fig. 1. Both base plate and cover plate are steel (A572 Gr.50).

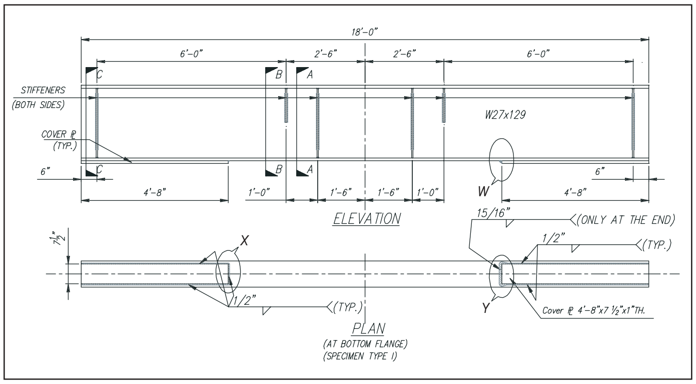

FIGURE 1. Partial details of one of the beam specimens being fatigue-tested at the ATLSS facility. The cover plate location is shown as "W" and "Y" on the right side.

Neutron diffraction measurements were made in a mesh, mostly near the weld toe, as indicated in Fig. 2. Overall, residual stresses were determined at 30 positions in the weld region, before and after UIT. Gauge volumes of 3 x 3 x 3 mm^3 (interior) and 2 x 2 x 2 mm^3 (near surface) were used. The unstressed *d*-spacing, d_0, was determined from a small piece of the starting material. The depth dependence of *X*-direction stresses is shown in Fig. 3.

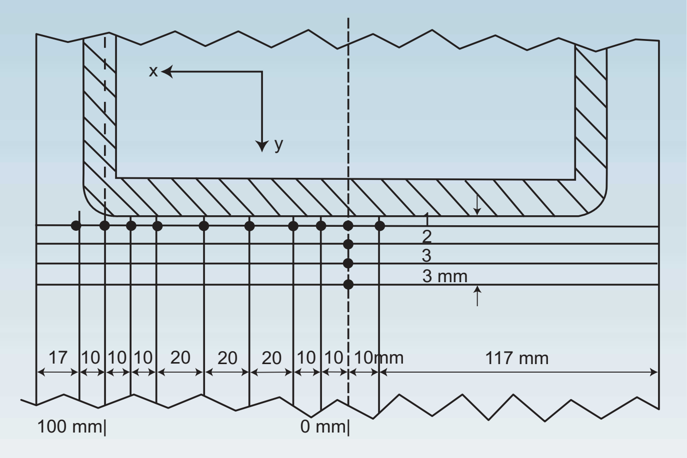

FIGURE 2. Top view of a flat test plate: cover plate (inner rectangular segment), weld (hatched area), and base plate underneath. Part of measurement mesh is shown by dots.

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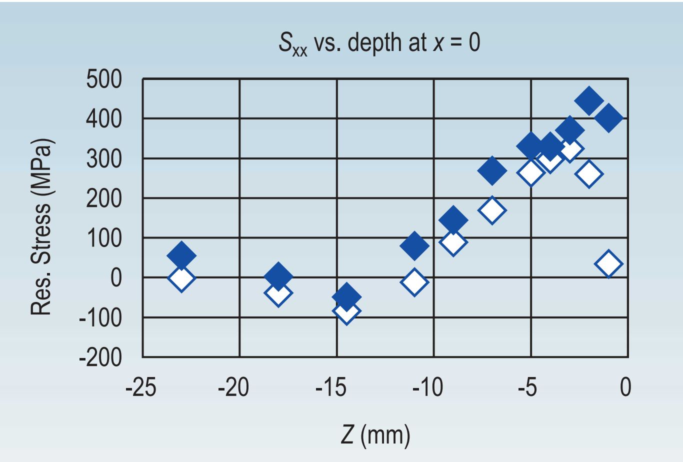

FIGURE 3. ***X*-direction residual stresses vs. depth at the weld center. Solid symbols are pre-UIT. Uncertainties are typically ± 20 MPa.**

The near-surface residual stresses determined, nominally 1 mm below the actual surface, are shown in Fig. 4. Both the anisotropy of stresses around the untreated weld metal, and the additional anisotropy introduced by UIT are seen. Before UIT, the stresses just beneath the weld toe are comparable and highly tensile in the *X* and *Y* directions. These stresses reach and exceed the minimum yield stress (315 MPa) of base plate material, whereas those normal to the surface are generally only ≈ 100 MPa tensile. After UIT the *X*-direction stresses become compressive, changing in magnitude by about 400 MPa. The *Y*-direction stresses are reduced by ≈ 150 MPa or less but remain in tension except at one point. The normal stresses (*Z*-direction) are essentially unchanged. The UIT effect on *X*-direction stresses (Fig. 3) is significant only near the plate surface, but reaches deeper than, for example, shot peening. The depth dependences of the *Y*- and *Z*-direction stresses were also obtained.

To our knowledge this is the first determination of the triaxial stress distribution in the vicinity of a weld treated with UIT. Having established the effects of UIT stress-relief on a test flange plate, ongoing neutron diffraction studies in this collaboration are now focusing on the mapping of stress gradients within and near weld joints in sections of actual fatigue-tested I-beams.

References

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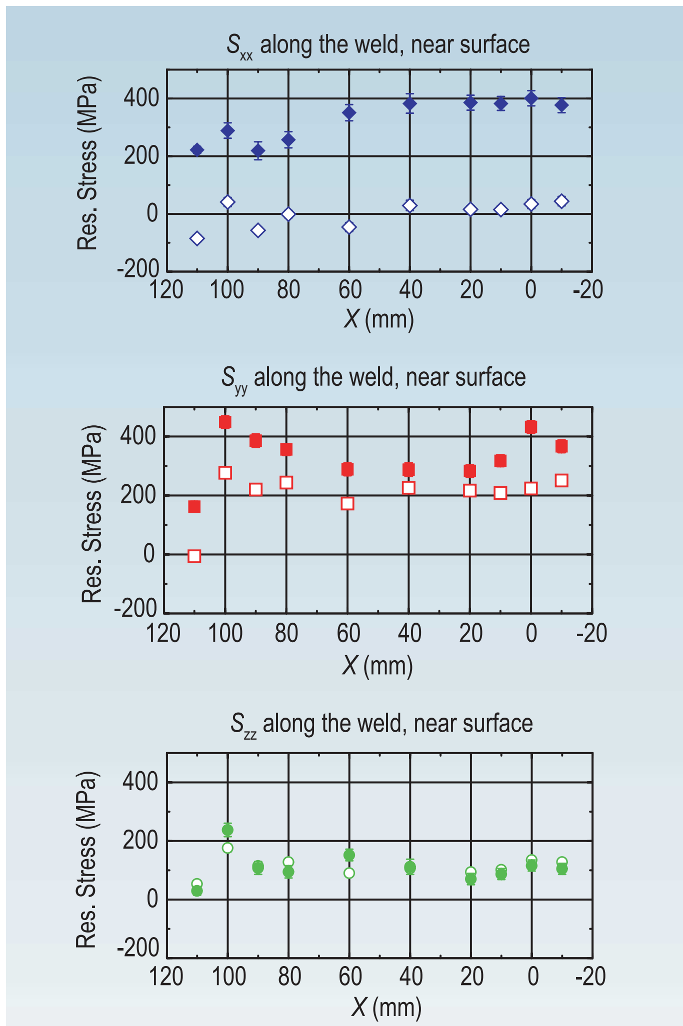

FIGURE 4. The residual stresses determined by neutron diffraction for the "near-surface" points. Uncertainties due to counting statistics are typically about ± 20 MPa. Solid symbols are before UIT.